CONTRACTOR: CONTINENTAL AMELIORATION RESEARCH ENVIRONMENTALISTS INT.
CONTRACT SERIAL NO. 23440-1-9024-01-SQ

MICROBIAL PLUGGING OF MINE WASTES TO REDUCE OR PREVENT THE GENERATION OF ACIDIC MINE DRAINAGE

FINAL REPORT

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Work on this project was conducted under the auspices of the Department of Energy, Mines and Resources

DSS FILE NUMBER: **38SQ.23440-1-9024**

DSS CONTRACT NUMBER: 23440-1-9024/01-SQ

CANMET PROJECT NUMBER:

CANMET SCIENTIFIC AUTHORITY: Dr. W.D. Gould

MICROMEDIA.

33 pp

EXECUTIVE SUMMARY

The introduction of exopolysaccharide producing ultramicrobacteria into the upper surface of both fine and coarse uranium mine tailings followed by the introduction of a rich microbial nutrient does produce an oxygen scavenging biobarrier. In the fine (slime) uranium tailings the microbial biobarrier resulted in the development of anaerobic conditions within the tailings column three weeks after introduction of the bacteria and the nutrient. In the fine tailings fraction the hydraulic conductivity of the tailings was reduced by 83-85% over a six week period of time. Unfortunately, the fine tailings provided by the mining company were not oxidized, but were fresh tailings from the mill, thus the initial pH of these tailings was >pH 7.0.

In columns of the coarse tailings fraction there was a substantial drop in the Eh of the column effluents with time and a concurrent increase in the pH of the effluents as the columns became anaerobic. Voids developed within these columns due to the microbial production of gases and there was no apparaent decrease in the hydraulic conductivity with time. Similarly, in the large lysimeters containing coarse uranium tailings, the microbial cap developed and produced anaerobic conditions at the surface but there was little or no change in the chemistry, Eh or pH of the effluents due to the extremely large volume of interstitial pore water.

The study was partially successful as it did indicate that a microbial biobarrier can be formed on the surface of tailings and can bring about changes in the Eh and pH of the effluents and, in the case of tailings of a fine particle size, can reduce the hydraulic

conductivity. The study also indicated that a cheaper, more viscous bacterial nutrient will be required for large scale application of the technology and that a continuous input of substrate carbon will be required to sustain a long term microbial biobarrier at the surface of a tailings impoundment. These deficiencies should be addressed at the outset of the next phase of the technology development-should further development be undertaken under the auspices of CANMET.

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MICROBIAL PLUGGING OF MINE WASTES TO REDUCE OR PREVENT THE GENERATION OF ACID MINE DRAINAGE

ULTRAMICROBACTERIA

Ultramicrobacteria (UMB's) are a natural occurrence in environments which are depleted of bacterial nutrients such as in the deep ocean, in deep underground aquifers, in deep aquifers associated with oil reservoirs etc. UMB's can be prepared in the laboratory or on a commercial scale using a patented process, which CARE International has exclusively licensed from AOSTRA. The bacterial cells are starved, under defined conditions, to produce cells which are 0.1 to 0.3 microns in size and which are completely devoid of their normal glycocalyx (polysaccharide capsular material). Normal vegetative bacterial cells quickly attach to surfaces due to the adhesive properties of the glycocalyx, thus if vegetative cells are introduced into a porous medium a surface bacterial plug is formed very quickly, but only in the first few centimeters of the porous material. In contrast, UMB's will migrate into porous matrices wherever the aqueous medium carrying them will migrate. If the UMB's are subsequently stimulated with a rich bacterial nutrient they will grow to their normal size and produce copious quantities of bacterial exopolysaccharides (glycocalyx) which will strongly bind them within the porous matrix. As the cells are alive and actively metabolizing they will quickly use the dissolved oxygen in the aqueous medium and the immediate environment will become anaerobic.

PREVIOUS STUDIES ON UMB'S

The UMB concept was developed and patented by Dr. J.W. Costerton and AOSTRA and has been assessed in columns and in an oil reservoir simulator as a means

of plugging off porous zones in petroliferous formations to prevent water bypass during secondary oil recovery. These studies were conducted under conditions in which the organisms and the nutrients were introduced into the sand-packs and the sandstone cores under pressure. Further, the pore size of the sand-packs and the Berea Sandstone Cores was one fifth to one twentieth the pore size of mine tailings. Further these sand-packs and Sandstone cores had interstitial void volumes of 10-12% and 2-5% respectively. In contrast, the void volume of the coarse uranium tailings utilized in this study are about 40% void space. Further complete plugging of the sandpacks and the Berea Sandstone cores required the throughput of 120-300 void volumes of bacterial nutrient.

HYPOTHESIS FOR THE MICROBIAL PLUGGING OF MINE TAILINGS

Mine tailings dumps are generally located in a valley or are contained within a large dam-like structure which have decant structures to allow water to drain from the waste. Unfortunately, as the water drains from the tailings it draws atmospheric oxygen into the tailings and this in turn reacts with the pyrite and pyrrhotite of the tailings to produce sulfuric acid and ferric sulphate. The ferric sulphate then chemically oxidizes any metal sulphides to sulphuric acid and free, soluble metal ions. This results in a drop in the pH within the tailings allowing growth of Thiobaccillus ferrooxidans which biologically catalyze the oxidation of pyrite and pyrrhotite at a rate 10^6 times greater than chemical pyrite oxidation at ambient temperatures and pressures. This biological oxidation of the metal sulphides results in further sulphuric acid generation and metal ion solubilization. The acidic drainage from sulphidic tailings is generally in the pH range of 1.8-3.2 and

contains up to 15,000 ppm of iron, 100-400 ppm of aluminum, copper, or zinc, and low levels of trace metals such as selenium, titanium, vanadium, arsenic or tellerium, depending on the type of ore that has been processed. In the case of uranium tailings, the acidic drainage will contain radio-active elements such as uranium, thorium, Pb^{210} and other decay products of the actinide series.

We postulate that by using UMB's we can calculate the volume of UMB suspension and bacterial nutrient solution required to form a continuous layer of bacteria and their associated polysaccharides which will actively remove oxygen from the air or precipitation entering the tailings. Further, this same layer of bacteria will gradually consume all of the oxygen from the interstitial water within the tailings pond, producing an anaerobic environment thereby reducing or preventing the oxidation of metal sulphides within the tailings and thereby prevent the formation of acid mine drainage.

MILL TAILINGS UTILIZED FOR THE STUDY

Twenty-three barrels of uranium mill tailings were obtained from Denison Mines in Elliot Lake, Ontario. One barrel contained the slime fraction of the milled tailings, but these were fresh and had not undergone weathering; thus their initial pH was >7.0. However, columns were set up using the slimes to assess the effect of bacterial capping in the slime fraction, even though in the field, the slimes in the tailings ponds are generally around pH 3.0-3.5. But the study was conducted to determine whether or not the UMB's could migrate into this finely sub-divided material and form a microbial plug thereby producing anaerobic conditions within the mill slimes.

The balance of the study was conducted on coarse uranium tailings and their

physical and chemical properties are outlined below:

PHYSICAL AND CHEMICAL PROPERTIES OF THE COARSE URANIUM TAILINGS

Physical Property	*Coarse Tailings*
% particles >0.02 mm (+300 mesh)	*40.0*
Particle density (g/cc)	*2.71*
Bulk density (g/cc)	*1.33*
Porosity (% pore space)	*41.*
Saturated Hydraulic Conductivity (cm/h)	*0.4-70.9 x 10^{-2} Average 11.4 x 10^{-2}*
Water Holding capacity (% by wt, 1/3 atm)	*7.3*
Air entry value (- cm H_2O)	*100.0*

Chemical Properties		*Coarse Tailings*
pH		*1.9*
Cation exchange capacity (meq/100 g)		*0.17*
Toxic metals (NH_4OAc Soln, ppm)	*Al*	*22.2*
	Fe	*250.0*
Available nutrients		
Nitrogen (NO_3, ppm)		*3.04*
Phosphorous ($NaHCO_3$ soln, ppm)		*0*
Exchangeable bases		
Acetate extract, meq/100g	*K*	*0.041*
	Ca	*7.61*
	Mg	*0.003*
Mineral content (% by weight)	*Si*	*41.3*
	Al	*2.0*
	S	*1.18*
	Fe	*1.15*
	K	*1.12*
	Ca	*0.28*
	Mg	*0.04*
Co_2, Mo,	*Pb*	*<0.05*
Ni, Cu, Zn, Mn, P,	*Cl*	*<0.01*

PREPARATION OF THE COLUMNS AND LYSIMETERS

To obtain packed columns and lysimeters of the tailings, the columns and lysimeters will filled with water to approximately one third their total volume. The damp uranium tailings were dispersed over the surface of the water and allowed to settle by gravity. When the required volume of tailings had been placed in the columns and lysimeters, the excess water was allowed to percolate through the tailings and discharge through the effluent collection port at the bottom of the columns or the lowest port on the large lysimeters.

CURRENT LABORATORY STUDIES

At present, CARE International is conducting column and lysimeter studies on the microbial plugging of uranium mill tailings. Three columns containing 1.5 Kg of the slime fraction (<400 mesh) of uranium mill tailings are being assessed; one column is an untreated control and two columns have been plugged utilizing UMB technology. The second series of columns is composed of three columns containing 1.5 Kg of coarse uranium tailings; again one column is an untreated control and two columns have been treated with the UMB technology. The third experiment utilizes three large lysimeters (127 cm x 67 cm x 90 cm), each containing about one tonne of coarse uranium tailings. Two of the lysimeters have been treated by the UMB technology to produce a 30 cm thick bacterial cap over the surface of the tailings, the other lysimeter is an untreated control. In all experiments water is applied weekly to simulate precipitation events and effluent samples from the columns and lysimeters are collected weekly. These samples are analyzed for pH, Eh and changes in the chemistry of the water.

RESULTS

I. SLIME COLUMNS

The study utilizing the slime fraction of the uranium tailings was not a good assessment of the ability of UMB's to establish a oxygen scavenging biological barrier over oxidized tailings as the slime sample received from the mine was directly from the mill and had an initial pH >7.0. The column study however strongly indicated the development of anaerobic conditions within the column, due to the blackening of the tailings and there was a significant reduction in the flow rate of the two microbially treated columns (See Figure 1). After 15 weeks, the columns were dismantled and analyzed for the bacterial numbers per gram of tailings and the amount of exopolymer carbohydrate/gram of tailings. The microbial counts in the two treated columns ranged from 1.7-3.5 x 10^7 aerobic and anaerobic organisms per gram of tailings. In comparison, the control column had bacterial counts of 8.9 x 10^6 for aerobic organisms and 4.4 x 10^6 for anaerobic organisms per gram of tailings or about one order of magnitude lower than the two treated columns. No bacterial exopolymer carbohydrates could be detected in the control column, whereas the two treated columns ranged from 2.1-3.6 ug of carbohydrate per gram of tailings.

II. COARSE TAILINGS COLUMNS

Attached are two figures showing the change in pH and in Eh of the effluents from the coarse uranium tailings columns. The pH and Eh of the control column effluent has shown only minor changes with time. In contrast, there has been a significant increase (4.5 orders of magnitude) in the pH of the effluent from the treated columns and a greater

than 90% decrease in the Eh (measure of dissolved oxygen) in the effluent from the treated columns (See Figures 2 & 3). In contrast to the slime columns studies in which there was a significant reduction in the flow rate of water through the microbially treated columns, this was not observed in the coarse tailings columns. This may be due to the bacterial production of carbon dioxide, as gas bubbles were observed in the treated tailings columns and distinct pores and fissures were observed in these columns due to the bacterial gas production. Further, these was the obvious odor of hydrogen sulphide which lead to the formation of black patches within the columns and indicated anaerobic conditions had developed allowing the reduction of sulphate to hydrogen sulphide by either facultative heterotrophic organisms, Clostridia or possibly anaerobic sulphate reducing organisms.

Core samples of the three coarse uranium tailings columns were collected after 5 weeks and again after 16 weeks for analyses of the number of bacteria per gram of tailings and the amount of bacterial polysaccharide per gram of tailings. After 5 weeks no bacteria could be detected in the untreated control column nor was any bacterial polysaccharide detectable. The aerobic bacterial counts in the two treated columns ranged from 7-42 x 10^7 organisms per gram of tailings and the carbohyudrate content of the tailings ramged from 10.6-17 ug carbohydrate per gram of tailings.

III. LARGE LYSIMETERS OF COARSE TAILINGS

Over the 131 days of the experiment no change in the flow rate of the tailings effluent, nor changes in the chemistry of the effluent from these lysimeters was noted. Forty-seven days after the experiment was initiated, core samples were obtained from the

surface of the lysimeters for bacterial and carbohydrate analyses. During the collection of these samples it was noted that the treated lysimeters had a 0.5-1.0 cm thick layer over the surface that had a consistancy similar to hard-boiled egg white. When the bacterial and carbohydrate analyses were received the bacteria were concentrated at the surface of the tailings and the carbohydrate content of this thin layer was six-fold to fifteen fold greater than the carbohydrate content at 15 cm depth. During the packing of the large lysimeters, the fine particles had floated to the surface producing a 0.5-1.0 cm layer over the surface of the tailings. The majority of the bacteria had become trapped in this layer and when stimulated with the nutrient produced exopolysaccharides which formed the rubbery surface plug.

This rubbery "skin-plug" associated with the fine tailings layer was broken down during the incorporation of the spent brewery grain into the surface layers of the two bacterially treated tailings. The hypothesis was that the spent brewery grain would act as a slow release bacterial nutrient. Within a few days of incorporating the spent brewery grain into the surface of the tailings in the lysimeters a 7-10 cm band of black, sulphide laden material developed on the surface of the two treated lysimeters. It appeared that a microbial cap could be formed over a larger surface area. However, as the volume of interstital water in the tailings within the lysimeters is greater than 300 liters and as the flow rate varied from 48-126 ml/min, a long period of time would be required to deplete or dilute the acidic interstitial water. Thus, changes in the chemistry of the interstitial water never became evident during the experiment.

A major problem which was observed in the use of the large lysimeters was the

fact that as the tailings settled and compacted within the large containers, the tailings material pulled away from the lysimeter tank walls allowing the ingress of oxygen to depth between the tailings mass and the walls of the lysimeter. In the field this problem would not occur as the tailings mass has never been observed to pull away from the dam-like enclosures.

Core samples were collected from the lysimeters after 5 weeks and 10 weeks for bacterial enumeration and carbohydrate analyses. No bacterial growth resulted from the plating out of samples from the surface or six inch depth of the control lysimeter. In the two microbially treated lysimeters the surface bacterial counts ranged from 1.8-3.2 x 10^5 cfu/g of tailings and the bacterial counts at six inches below the tailings surface ranged from 1.3 to 8.0 x 10^4 cfu/g of tailings. The surface carbohydrate content in the treated lysimeters ranged from 30-33.l ug carbohydrate/ gram of tailings but dropped to 2.0-5.0 ug carbohydrate/g of tailings at 6 inches depth (see discussion above regarding a thin rubbery layer). A few days after these core samples were collected, spent brewery grain was incorporated into the surface of the two bacterially treated lysimeters as a potential slow-release substrate. The input of the spent brewery grain resulted in a substantial increase in the bacterial numbers in samples collected five weeks later as well as a five to six fold increase in the carbohydrate content of the tailings over the same time frame. The addition of the spent brewery grain also stimulated the growth of anaerobic sulphate reducing bacteria in the surface layer of the lysimeters as they were not detected in the analyses conducted five weeks earlier.

MICROBIAL AND CARBOHYDRATE CONTENT OF THE LYSIMETER TAILINGS

(samples collected 3 weeks after addition of spent brewery grain)

	ug. CHO/g tails	*Aerobes*	*Anaerobes*	*SRBs*
Control	*3.2*	*nil*	*nil*	*nil*
Treated Lys. A	*150*	4.1×10^7	1.1×10^8	$>1.4 \times 10^7$
Treated Lys. B	*170*	3.3×10^5	3.9×10^5	4.5×10^4

RESEARCH REQUIRED TO OPTIMIZE THE PROCESS

1. The nutrients utilized to stimulate the reversion of UMB's to vegetative cells in the current study are too expensive for use on an industrial scale. An inexpensive food industry waste stream, rich in sugars, amino acids and/or proteins must be found as a nutrient.
2. The resucitative nutrient must have a level of viscosity that is high enough to prevent its immediate passage or leaching through the tailings and reporting to the effluents.
3. There is a need to assess the immediate development of a vegetative cover over the tailings immediately after the microbial cap is formed. This may accomplish three things: 1. The root exudates from the vegetative cover may provide a slow-release carbon source which would sustain the microbial cap indefinitely. 2. The vegetative cover would prevent or reduce the drying out of the tailings surface and prevent ultraviolet light from inhibiting the bacterial cover. 3. The vegetative cover would reduce the dusting and wind erosion of the surface of the tailings and would make the surface of the tailings more aesthetically pleasing to passersby.

CONCLUSIONS

Although the current study has brought to light unanticipated problems in the development of an oxygen-scavenging, microbial cap on the surface of uranium mill tailings as indicated in the previous section. The results to date on the UMB plugging of mine tailings are very encouraging; especially when one considers the chemically hostile environment in which the organisms were initially placed. The fact that we have been able to establish a UMB microbial cap under extremely acidic conditions in the presence of highly toxic radio-active elements strongly implies that this technology will be applicable to other industrial problems. One can immediately anticipate utilizing this technology to:

(1) Provide a living biological barrier around land-fill sites to remove metal ions and organic pollutants from the effluents.

(2) Provide a living biological barrier around leaking underground storage tanks to prevent the spreading of the pollutant plume and possibly biologically degrade the pollutant organics. The biobarrier technology could also be applied in a proactive manner, that is, the barrier would be produced at the time of the storage tank installation. If the tank should rupture or corrode, the barrier would then contain the contents in the immediate vicinity of the tank, and prevent extensive pollution of the underground environment.

(3) As an active biological barrier in waste disposal ponds in the pulp and paper industry.

(4) As an active biological barrier in sump ponds and waste disposal ponds in the petroleum sector.

These are some of the applications that are foreseen at the present time for this

unique technology. As more research and development of the technology proceeds, further applications may become apparent.

FIGURES

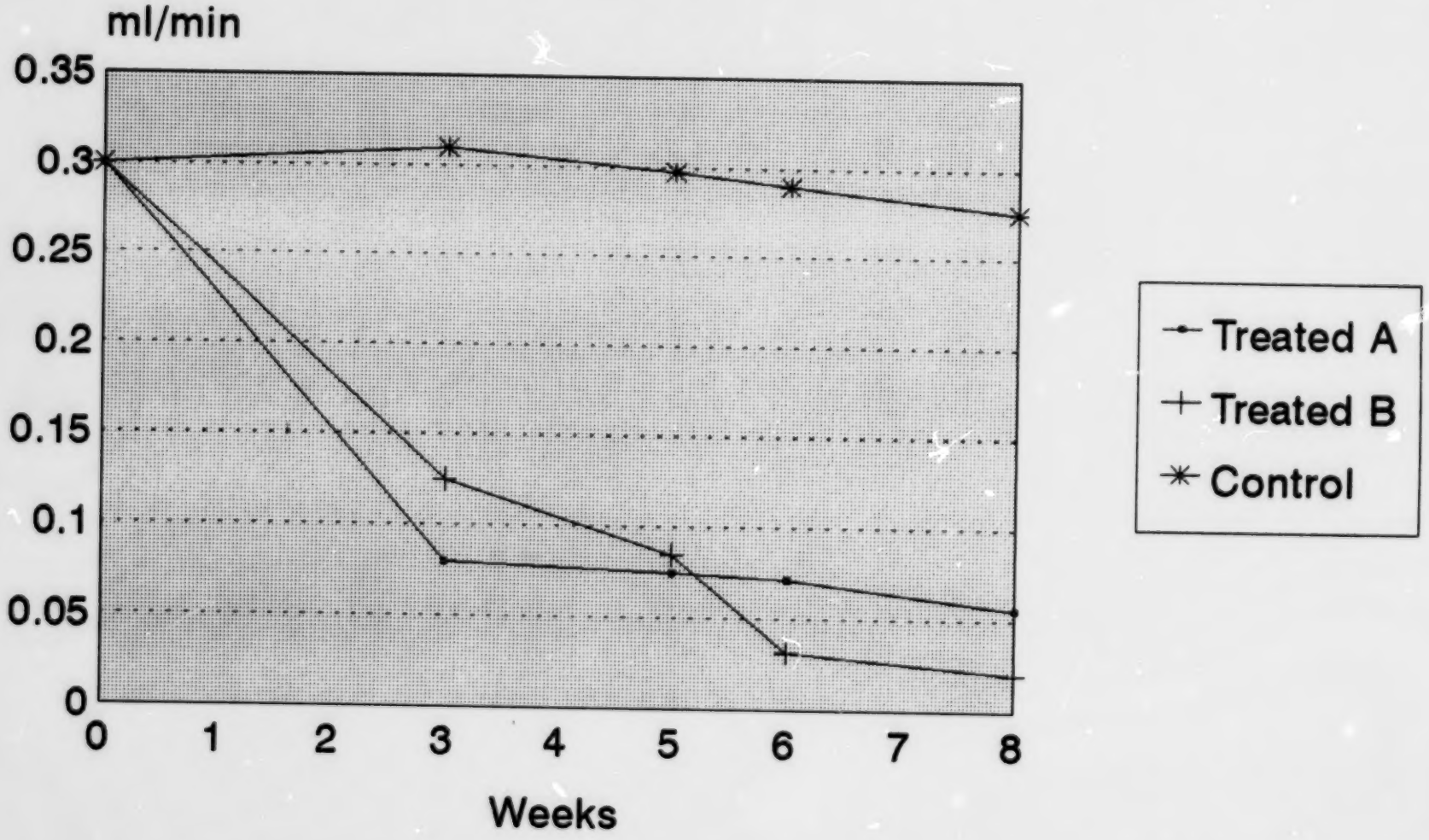
Figure 1. Effect of microbial plugging on the effluent flow rate in the slime fraction of Denison Elliot Lake tailings.

Figure 2. The effect of microbial plugging on the Eh of the effluent from coarse uranium tailings.

Figure 3. The effect of microbial plugging on the pH of the effluent from coarse uranium tailings.

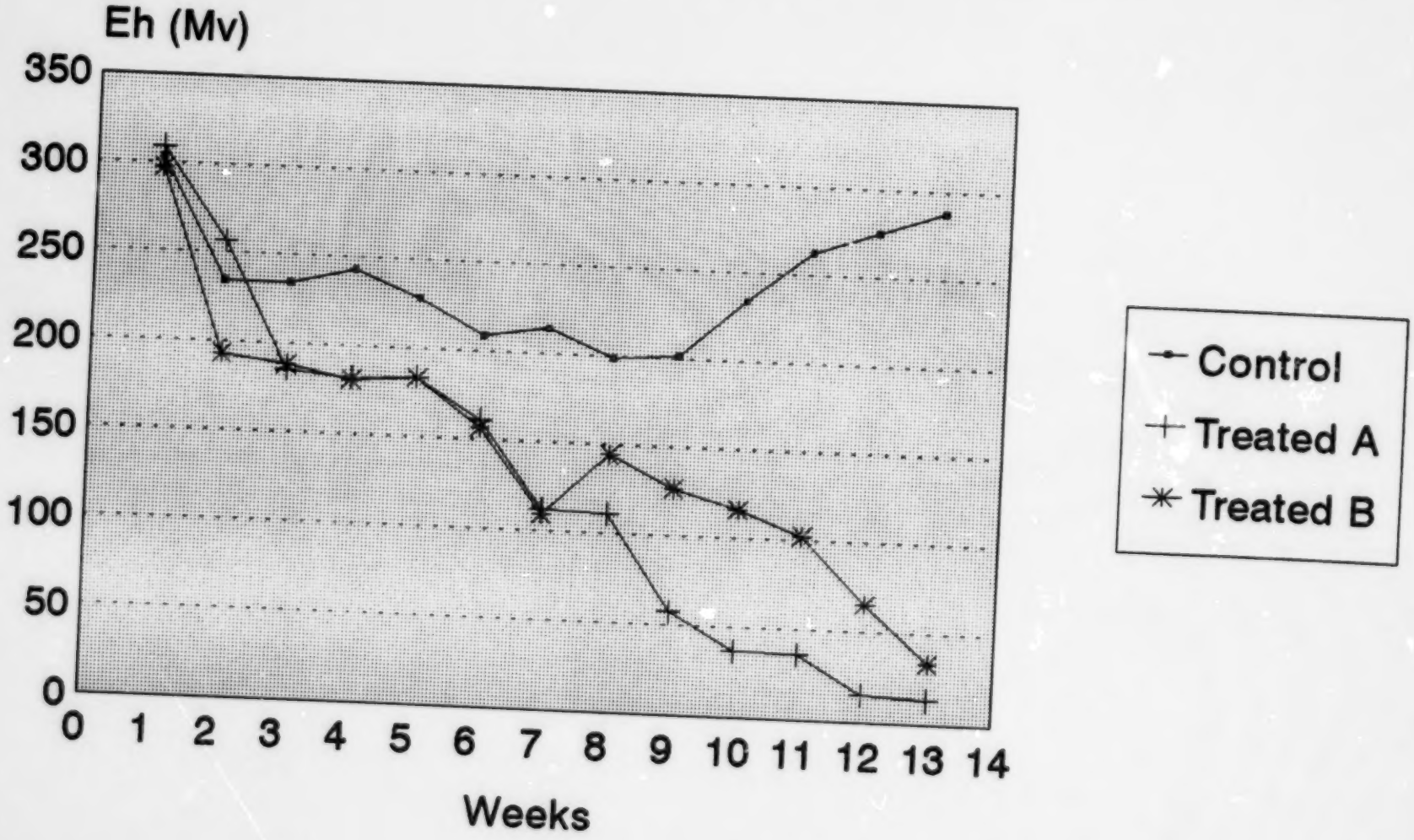
Flowrate of Tailings Effluents

Slime Fraction: Uranium Tailings



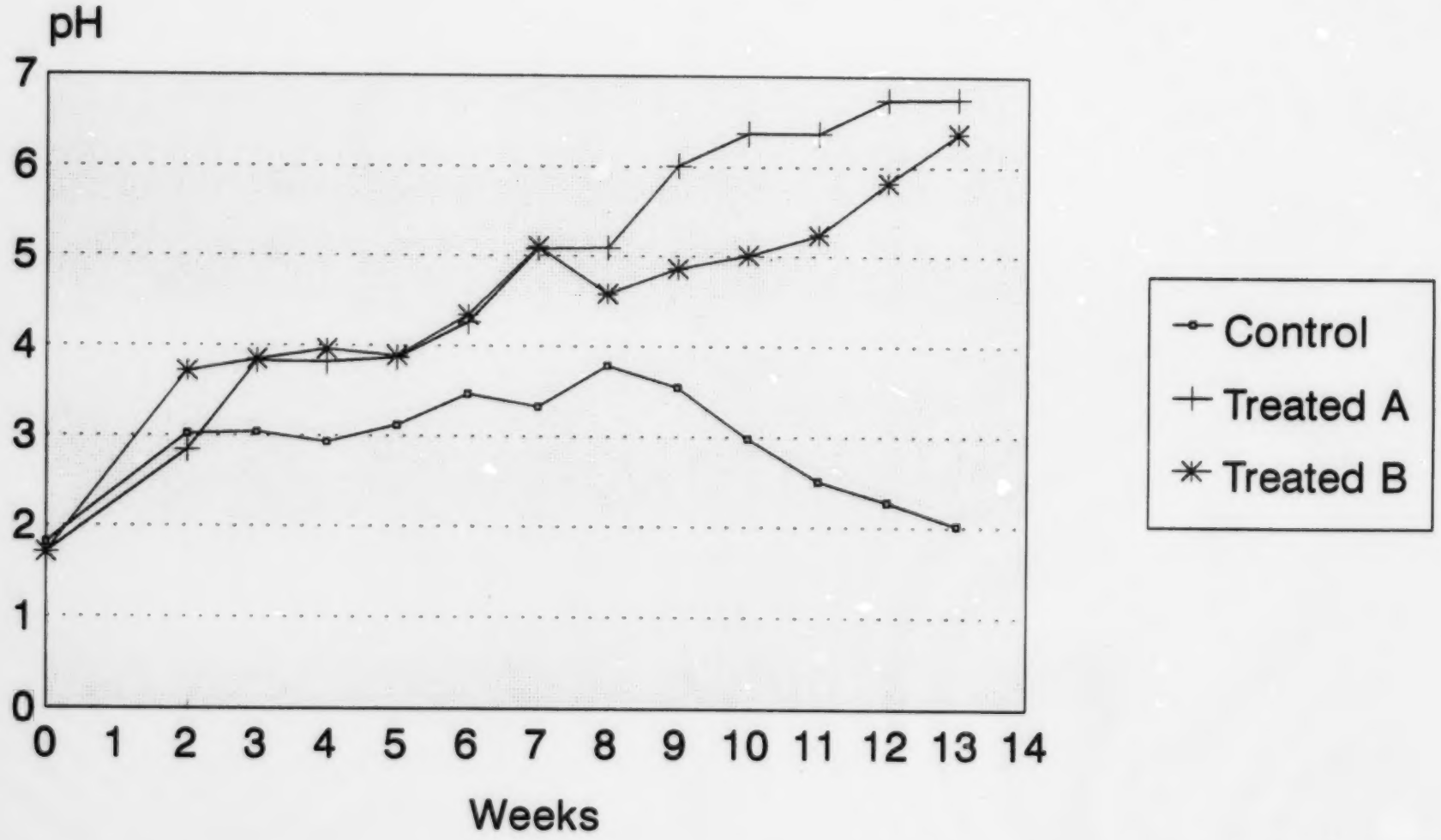
Eh of Effluents

Coarse Tailings Columns



pH of Effluent

Coarse Tailings Columns



APPENDIX

TABLES OF DATA COLLECTED FROM THE VARIOUS EXPERIMENTS

***LARGE LYSIMETERS** (~ONE TONNE OF COURSE TAILINGS)*

FLOWRATE:	**treated**	**treated**	**control**
0 time	*nd*	*7 ml/min*	*2.7 ml/min*
22 days	*63ml/min*	*35ml/min*	*9.6ml/min*
35 days	*126ml/min*	*70 ml/min*	*50 ml/min*
41 days	*48 ml/min*	*21 ml/min*	*37.5 ml/min*
47 days	*109 ml/min*	*176 ml.min*	*94 ml/min*
(top of treated lysimeters disturbed due to incorporation of brewery spent grain)			
24/9/91	*92 ml/min*	*144 ml/min*	*N/A*
30/9/91	*100 ml/min*	*176 ml.min*	*N/A*
7/10/91	*95 ml/min*	*125 ml/min*	*N/A*
15/9/91	*106 ml/min*	*118 ml/min*	*N/A*
21/10/91	*59 ml/min*	*52 ml/min*	*N/A*
28/10/91	*88 ml/min*	*187 ml/min*	*N/A*
4/11/91	*40 ml/min*	*90 ml/min*	*N/A*
12/11/91	*42 ml/min*	*86 ml/min*	*92 ml/min*
26/11/91	*40 ml/min*	*90 ml/min*	

pH OF EFFLUENT

Time	**treated**	**treated**	**control**
0 time	*1.97*	*2.36*	*2.39*
8 days	*1.96*	*2.11*	*1.82*
16 days	*2.01*	*2.19*	*1.93*
22 days	*2.04*	*2.18*	*2.02*
29 days	*1.87*	*2.05*	*1.85*
35 days	*1.89*	*2.12*	*1.99*
41 days	*1.90*	*2.23*	*2.00*
47 days	*1.94*	*2.15*	*2.02*
61 days	*1.99*	*2.17*	*2.04*
68 days	*1.98*	*2.14*	*2.02*
75 days	*2.04*	*2.15*	*2.01*
82 days	*1.85*	*1.94*	*1.85*
88 days	*1.87*	*2.03*	*1.84*
95 days	*1.9*	*1.97*	*1.88*
102 days	*1.9*	*2.01*	*1.91*
110 days	*1.87*	*1.98*	*1.92*
117 days	*1.84*	*2.0*	*1.98*
124 days	*1.94*	*2.14*	*2.06*
131 days	*1.90*	*2.01*	*1.9*

Eh of Effluent (mV)

Time	**treated**	**treated**	**control**
0 time	*298.4*	*276.9*	*273.8*
8 days	*311.0*	*301.5*	*319.5*
16 days	*307.4*	*297.0*	*312.2*
22 days	*304.4*	*297.8*	*306.3*
29 days	*316.4*	*305.4*	*318.2*
35 days	*311.4*	*304.2*	*309.3*
41 days	*314.9*	*295.6*	*308.6*
47 days	*310.7*	*298.3*	*307.9*

61 days	308.6	293.6	306.0
68 days	309.9	299.1	306.9
75 days	305.7	300.7	307.9
82 days	299.6	295.8	300.2
88 days	298.7	293.0	301.7
95 days	297.2	293.8	299.4
102 days	300.5	291.0	297.0
110 days	300.6	292.7	296.0
117 days	303.6	294.7	297.1
124 days	312.4	299.8	305.1
131 days	300.5	291.0	297.0

Precipitation Events:

Time	**treated**	**treated**	**control**
0 time	47 litres	47 litres	39 litres (water)
(1% sucrose and 0.1 brain heart infusion)			
7 days	1.16 L	1.16 L.	0.97 L (all water)
14 days	2.32 L	2.32 L	0.97 L (all water)
15 days	3.0 L	3.0 L	3.0 L (all water)
21 days	3.0 L	3.0 L	2.5 L (all water)
28 days	46 L*	46L*	39 L (water)
35 days	3 L	3 L	3 L (all water)
* 1% sucrose			
42 days	3 L	3 L	3 L

6/9/91 Added spent brewery grain to treated lysimeters, incorporated in top 7.5-10 cm. of the tailings.
6/9/91 Added 3 L of water to each of the lysimeters.
9/9/91 Added 10 L of water to each lysimeter....some fungal growth on the surface of the two treated lysimeters.
19/9/91 Added 4 L of water to the two treated lysimeters. Control lysimeter cracked in corner, water flows out freely.
30/9/91 (68 days) added 4L/lysimeter
99 days....lysimeters drained to bottom outlet...10 L of water added to each lysimeter.
18/11/91 Added 4 L of water to all lysimeters
19/11/91 Drain all lysimeters, added 10 L of water to each

Chemistry of the Effluents:

		Sulfate g/L	Total Fe ppm	Fe^{2+} ppm	U ppm	Th ppm
Treated(A)	18/7/91	4.218	850	757	<0.5	<0.5
Treated (b)	18/7/91	2.401	378	329	"	"
Control (C)	18/7/91	2.311	322	308	"	"
Treated (A)	31/7/91	5.16	1140	1095	<0.5	<0.5
Treated (B)	31/7/91	3.78	770	776	2.51	<0.5
Control (C)	31/7/91	6.80	1530	1527	<0.5	<0.5
Treated (A)	8/8/91	5.52	1290	911	<0.5	<0.5
Treated (B)	8/8/91	3.72	810	794	6.34	<0.5
Control (C)	8/8/91	7.40	1870	1774	<0.5	<0.5

Treated (A)14/8/91	4.88	1210	1208
Treated (B)14/8/91	3.86	905	889
Control (C)14/8/91	6.01	1510	1340
Treated (A)22/8/91	6.46	1710	1700
Treated (B)22/8/91	5.21	1415	1413
Control (C)22/8/91	7.35	1980	1977
Treated (A)28/8/91	7.81	2370	2322
Treated (B)28/8/91	4.92	1385	1193
Control (C)28/8/91	6.08	1770	1720
Treated (A) 3/9/91	N.D.	2690	2411
Treated (B) 3/9/91	3.73	1015	889
Control (C) 3/9/91	5.83	1860	1753
Treated (A) 10/9/91	7.35	850	
Treated (B) 10/9/91	3.98	2400	
Control (C) 10/9/91	5.72	1760	
Treated (A) 24/9/91	7.21	2277	2244
Treated (B) 24/9/91	4.90	1408	1386
Control (C) 24.9.91	6.02	1826	1804
Treated (A) 2/10/91	6.87	2450	1760
Treated (B) 2/10/91	5.13	1780	1240
Control (C) 2/10/91	6.07	2050	1520

Lysimeter A is 127 cm x 61 cm with 122 cm of tailings inside.
Lysimeter B is 127 cm x 61 cm with 97 cm of tailings inside.
Lysimeter C is 116 cm x 56 cm with 120 cm of tailings inside.

For nutrient addition, we calculated the length times width times 30 cm times 0.2 (assumed 20% void space in the packed tailings).

First nutrient addition was 1/10 strength brain heart infusion plus 1% sucrose, applied July 23/91. Second addition (August 19/91 was 1% sucrose. September 6/91...35 lbs.(15.876 Kg) of spent brewery grain (Great Lakes Brewery Ltd.) was incorporated into the top 7.5-10 cm of the tailings in lysimeters A & B. 3 L. of tap water was applied to the surface of all three lysimeters.

Cores taken on 4/9/91 and sent to Calgary for analyses.

Bacterial Counts and Carbohydrate Concentration

	CHO(ug/g W/W)	Aerobes	Anaerobes
Treated A (top)	33.1	1.8×10^5	N.D.
Treated A (6")	5.0	8.0×10^4	N.D.
Treated B (top)	30.0	3.2×10^5	N.D.
Treated B (6")	2.0	1.3×10^4	N.D.

Control	*nil*	*nil*

Bacterial Counts and Carbohydrate Concentration *(Oct. 30/91)*

	CHO (ug/g W/W)	Aerobes	Anaerobes	SRB's
Treated A	*150*	4.1×10^7	1.13×10^8	$>1.4 \times 10^7$
Treated B	*170*	3.3×10^5	3.9×10^5	4.5×10^4
Control	*3.2*	*nil*	*nil*	*nil*

Bacterial counts are cfu's/g of tailings
Aerobes and anaerobes determined on 1/10 BHI + 1% sucrose
SRB's determined on Butlin's medium and calculated by MPN.

Course Tailings Columns: 6.2 cm diameter (ID) x 31 cm height containing 1500 gm. of course tailings.

Flow Rate:

Columns inoculated July 26/91 with 100 ml. of bacteria and 250 ml. of BHI and Sucrose.

30/7/91	*Column 1 (Control)*	*4.4 ml/min*
	Column 2 (Treated)	*7.4 ml/min*
	Column 3 (Treated)	*5.4 ml/min*
15/8/91	*Column 1 (Control)*	*10.1 ml/min.*
	Column 2 (Treated)	*6.2 ml/min*
	Column 3 (treated)	*4.4 ml/min.*
27/8/91	*Column 1*	*2.07 ml/min*
	Column 2	*1.33 ml/min*
	Column 3	*1.08 ml/min*
3/9/91	*Column 1*	*7.25 ml/min*
	Column 2	*4.8 ml/min*
	Column 3	*2.48 ml/min*
9/9/91	*Column 1*	*10.7 ml/min*
	Column 2	*5.0 ml/min*
	Column 3	*2.8 ml/min*
23/9/91	*Column 1*	*7 ml/min*
	Column 2	*5 ml/min*
	Column 3	*3 ml/min*
30/9/91	*Column 1*	*11.6 ml/min*
	Column 2	*9.9 ml/min*
	Column 3	*8.2 ml/min*
7/10/91	*Column 1*	*3.0 ml/min*
	Column 2	*3.6 ml/min*
	Column 3	*3.5 ml/min*
15/10/91	*Column 1*	*6.0 ml/min*
	Column 2	*5.3 ml/min*
	Column 3	*4.0 ml/min*
21/10/91	*Column 1*	*6.4 ml/min*
	Column 2	*4.0 ml/min*
	Column 3	*3.4 ml/min*
28/10/91	*Column 1*	*4.6 ml/min*
	Column 2	*3.55 ml/min*
	Column 3	*3.4 ml/min*
4/11/91	*Column 1*	*7 ml/min*
	Column 2	*6 ml/min*
	Column 3	*4.75 ml/min*

12/11/91	Column 1	7.5 ml/min
	Column 2	6.0 ml/min
	Column 3	4.75 ml/min

pH of Effluents

Date	Column 1	Column 2	Column 3	
18/7/91	1.82	1.71	1.71	
31/7/91	3.02	2.84	3.72	
8/8/91	3.04	3.83	3.85	
14/8/91	2.93	3.82	3.96	
21/8/91	3.12	3.87	3.89	
27/8/91	3.47	4.26	4.34	
3/9/91	3.33	5.08	5.10	(strong H_2S smell...treated columns)
9/9/91	3.79	5.09	4.58	
23/9/91	3.55	6.01	4.86	
30/9/91	2.98	6.37	5.01	
7/10/91	2.51	6.37	5.24	
15/10/91	2.28	6.74	5.83	
22/10/91	2.02	6.75	6.37	
28/10/91	1.87	6.62	6.47	
4/11/91	1.85	6.34	6.67	
12/11/91	1.84	5.73	6.65	
18/11/91	1.90	4.93	6.65	
25/11/91	2.0	3.88	6.67	
2/12/91	2.18	3.93	6.48	

Eh of Effluents (mV):

Date	Column 1	Column 2	Column 3
28/7/91	303.1	308.9	297.2
31/7/91	234.0	256.4	193.1
8/8/91	234.2	185.5	188.3
14/8/91	242.9	182.2	181.1
21/8/91	228.3	183.9	183.7
27/8/91	208.8	161.1	156.8
3/9/91	214.1	112.5	109.5
9/9/91	199.1	111.1	144.5
23/9/91	201.8	57.7	126.8
30/9/91	233.9	36.9	116.2
7/10/91	262.5	36.3	102.6
15/10/91	275.5	15.4	65.6
22/10/91	287.9	13.5	33.8
28/10/91	299	18.8	30.4
4/11/91	301.1	34.8	14.6
12/11/91	302.4	72.2	20.7
18/11/91	300.3	122.3	17.7
25/11/91	293.9	171.0	17.6
2/12/91	284	179	30.2

Precipitation Events:

26/7/91 Inoculated and nutrient addition; 350 mls to each column
28/7/91 Added 250 mls 0.37% BHI &1% sucrose to each column
29/7/91 Added 1.83 ml water to each column
30/7/91 added 100 ml. water to each column
7.8.91 added 40 ml. water to column 2 & 3
12/8/91 added 200 ml. water to all columns
19/8/91 Added 350 ml. 1% sucrose to 2 &3, 350 ml water to 1.
16/8/91 Added 100 ml. water to columns 1, 2 & 3.
26/8/91 Added 150 ml. water to columns 1, 2 & 3.
29/8/91 Added 200 ml to Col. 2 and 100 mls to Col. 3.
3/9/91 Added 70 ml. water to columns 2 & 3; 50 mls to #1)
9/9/91 Added 50 ml. water to columns 1, 2 & 3.
23/9/91 Added 100 ml. water to Columns 1, 2 & 3.
30/9/91 Added 50 ml to Coumns 2 & 3.
8/10/91 Added 50 ml water to Column 2.
4/11/91 Added 70 ml water to columns 1,2 & 3.
19/11/91 100 ml water to all three columns.
25/11/91 75 ml water added to all three columns

Chemistry of Effluents

	Sulfate g/L	Total Fe ppm	Fe^{2+} ppm	U ppm	Th ppm
Column 1: 26/7/91	4.81	860	9.6	<0.5	<0.5
Column 2: 26/7/91	4.39	785	8.2	"	"
Column 3: 26/7/91	3.06	433	134	"	"
Column 1: 31/7/91	1.51	17.0	10.3	<0.5	<0.5
Column 2: 31/7/91	2.14	35.4	31.6	"	"
Column 3: 31/7/91	1.94	6.2	4.7	"	"
Column 1: 8/8/91	1.58	40.0	31.0	<0.5	<0.5
Column 2: 8/8/91	1.79	15.1	15.1	"	"
Column 3: 8/8/91	1.71	11.1	8.2	"	"
Column 1: 14/8/91	1.58	37.8	24.7		
Column 2: 14/8/91	1.73	13.6	11.6		
Column 3: 14/8/91	1.71	15.0	12.9		
Column 1: 22/8/91	1.59	78.2	73.8		
Column 2: 22/8/91	1.52	29.2	24.4		
Column 3: 22/8/91	1.53	22.2	20.2		
Column 1: 28/8/91	1.53	3.9	1.2		
Column 2: 28/8/91	1.49	110.0	107.0		
Column 3: 28/8/91	1.51	75.0	72.9		
Column 1: 3/9/91	1.50	5.6	1.6		
Column 2: 3/9/91	1.44	259.0	254.0		
Column 3: 3/9/91	1.40	144.0	142.0		

Cores taken on 4/9/91 and sent to Calgary for analyses.

Column 1: 10/9/91	1.63	13	
Column 2: 10/9/91	1.39	155	
Column 3: 10/9/91	1.53	183	
Column 1: 24/9/91	1.53	77	66
Column 2: 24/9/91	1.31	99	22
Column 3: 24/9/91	1.59	330	330
Column 1: 2/10/91	1.66	26	4.7
Column 2: 2/10/91	1.28	64	1.9
Column 3: 2/10/91	1.62	314	267
Column 1: 25/11/91		1269	
Column 2: 25/11/91		128	
Column 3: 25/11/91		0.6	

Cores taken on Oct 29/91...sent to Calgary for analyses.

Bacterial Counts and Carbohydrate Concentration

	CHO (ug/g wet wt.)	Aerobes	Anaerobes
Control	nil	nil	N.D.
Treated A	10.6	7×10^7	N.D.
Treated B	17.0	4.2×10^8	N.D.

SLIME COLUMNS (6.2 cm diameter (ID) x 27cm height containing 1500 g of slimes.

Flow Rates:

24/7/91	*Column 4 (treated)*	*0.3 ml/min*
	Column 5 (treated)	*0.1 ml/min*
	Column 6 (control)	*0.3 ml/min.*

Columns inoculated and purged with nutrients on 26/7/91.

15/8/91	*Column 4 (treated)*	*0.06 ml/min*
	Column 5 (treated)	*0.125 ml/min*
	Column 6 (control)	*0.28 ml/min*

Obvious blackening was observed on the surface of Columns 4 & 5 on 7/8/91 and has progressed deeper with time and darkening continues to occur. Core samples of slime columns collected 21/8/91 and sent to Calgary for bacterial counts and slime production/g of slimes.

27/8/91	*Column 4*	*0.075 ml/min*
	Column 5	*0.058 ml/min*
	Column 6	*0.285 ml/min*
9/9/91	*Column 4*	*0.0916 ml/min*
	Column 5	*0.0316 ml/min*
	Column 6	*0.283 ml/min (algae present)*
23/9/91	*Column 4*	*0.056 ml/min*
	Column 5	*0.0208 ml/min*
	Column 6	*0.283 ml/min*
30/9/91	*Column 4*	*0.05 ml/min*
	Column 5	*0.016 ml/min*
	Column 6	*0.238 ml/min*
7/10/91	*Column 4*	*0.05 ml/min*
	Column 5	*0.02 ml/min*
	Column 6	*0.27 ml/min*
15/10/91	*Column 4*	*0.06 ml/min*
	Column 5	*0.02 ml/min*
	Column 6	*0.28 ml/min*
22/10/91	*Column 4*	*0.045 ml/min*
	Column 5	*0.0175 ml/min*
	Column 6	*0.275 ml/min*
28/10/91	*Column 4*	*0.056 ml/min*
	Column 5	*0.02 ml/min*
	Column 6	*0.268 ml/min*

Precipitation Events:

3/9/91 Added 50 ml. water to Columns 4, 5 & 6.
30/9/91 Added 50 ml of water to Column 6.

2/10/91 Added 50 ml water to columns 4,5 & 6.
8/10/91 Added 50 mls Water to columns 4 & 5.

pH and Eh (mV) of Effluents:

		pH	Eh	
28/7/91	Column 4	7.21	-17.2	
	Column 5	7.20	-11.7	
	Column 6	7.64	-38.2	
31/7/91	Column 4	5.73	75.9	
	Column 5	6.24	41.1	
	Column 6	7.33	-28.3	
8/8/91	Column 4	7.69	-40.0	
	Column 5	7.84	-48.7	
	Column 6	7.41	-24.6	
14/8/91	Column 4	7.44	-29.0	
	Column 5	7.45	-28.1	
	Column 6	7.25	-13.8	
21/8/91	Column 4	7.13	- 9.3	
	Column 5	7.35	-20.3	
	Column 6	6.58	+26.4	
28/8/91	Column 4	7.64	-42.8	
	Column 5	7.38	-22.0	
	Column 6	6.93	- 5.8	
3/9/91	Column 4	7.52	-36.5	
	Column 5	7.48	-29.4	
	Column 6	7.80	-48.1	
	Algal growth noted in Column 6.			
9/9/91	Column 4	7.46	-36.5	
	Column 5	7.58	-34.1	
	Column 6	7.65	-35.6	(extensive algal growth)
23/9/91	Column 4	7.94	-56.5	
	Column 5	8.02	-60.3	
	Column 6	8.24	-73.3	
30/9/91	Column 4	7.44	-21.5	
	Column 5	7.72	-33.7	
	Column 6	8.48	-81.1	
7/10/91	Column 4	7.60	-41.2	
	Column 5	7.89	-52.7	
	Column 6	8.42	-81.0	
15/10/91	Column 4	8.03	-57.8	
	Column 5	7.75	-41.8	
	Column 6	7.92	-54.7	

22/10/91	Column 4	7.82	-52.0
	Column 5	7.80	-32.0
	Column 6	8.59	-86.6
28/10/91	Column 4	7.91	-54.0
	Column 5	8.14	-65.9
	Column 6	8.14	-71.6

Experiment terminated as plugging has been successful.

Chemistry of the Effluents:

		Sulfate g/L	total Fe ppm	Fe^{2+} ppm	U ppm	Th ppm
27/7/91	Column 4	2.33	<0.1	<0.1	2.93	<0.5
	Column 5	1.97	"	"	0.83	"
	Column 6	2.58	"	"	2.08	"
31/7/91	Column 4	1.64	2.68	2.46	<0.5	<0.5
	Column 5	1.80	0.63	0.59	"	"
	Column 6	1.85	<0.1	<0.1	1.50	"
8/8/91	Column 4	1.73	<0.1	<0.1	3.76	<0.5
	Column 5	1.75	"	"	3.77	"
	Column 6	1.67	"	"	3.14	"
14/8/91	Column 4	1.73	0.2	0.2		
	Column 5	1.82	<0.1	<0.1		
	Column 6	1.67	0.2	0.2		
22/8/91	Column 4	1.53	0.2	0.2		
	Column 5	1.73	0.3	0.2		
	Column 6	1.62	0.2	0.1		

29/8/91 Flowrate on slime columns too low to collect samples for chemical analyses.

3/9/91	Column 4	1.74	0.2	0.2
	Column 5	1.61	0.5	0.5
	Column 6	9.73	<0.1	<0.1
10/9/91	Column 4	1.44	1.2	
	Column 5	1.45	1.7	
	Column 6	1.54	0.06	
24/9/91	Column 4	1.57	<0.1	<0.1
	Column 5	1.62	<0.1	<0.1
	Column 6	1.69	<0.1	<0.1
2/10/91	Column 4	1.65	73	1.9
	Column 5	1.59	73	0.95
	Column 6	1.64	132	4.7

Bacterial Counts and Carbohydrate Concentration

	CHO (ug/g Wt. W)	Aerobes	Anaerobes
Treated A	3.6	3.5×10^7	2.15×10^7
Treated B	2.1	2.6×10^7	1.7×10^7
Control	nil	8.9×10^6	4.4×10^6